REVISTA DE
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Modeling of Equivalent Effective Temperature and its possible incidence on larval density of *Anopheles* mosquitoes (Diptera: Culicidae) in Villa Clara province, Cuba

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Abstract: The wind chill or Equivalent Effective Temperature (EET) is the thermic sensation that a person feels when being exposed to a certain combination of temperature from the air, relative humidity and wind velocity. The objective of this investigation was directed to determine the possible incidence of the EET upon the larval density of *Anopheles* mosquitoes in Villa Clara province, Cuba. The Climatological data were compiled from the Yabú station in Santa Clara, and a total of 5 370 measurements were included in a database every three hours, using the aggregate function of the Statistical Package of Social Science software version 13 (SPSS), from January 1st, 2011 to September 30th, 2013. A long term forecast (1 year of advance) was made to obtain EET and the *Anopheles* larval density in the locality of Santo Domingo was modelled. These entomological data were taken at the same time but monthly, so the EET data were converted to monthly scale to be correlated with the monthly data of the larval density. The result was a 97.1 % of variance with a standard error (SE) of 3.57 °C for the model of the EET with a year of anticipation; therefore, the tendency in time was significant. The modeling also included the *Anopheles* larval density of mosquitoes in Santo Domingo, Villa Clara province, observing an increase of the EET, while the *Anopheles* mosquito larvae also increased. The most important variables in the model were the EET that were back in 1, 2, 3, 4, 7, 16, 24, 40 for the previous year; that is to say 2 920, 2 921, and so on, which explained a strong contagion among the data. EET correlation compared with itself in previous year was high; therefore, it may be used as a predictable variable. The anophelinic density in Santo Domingo explained the 66 % of the variance, with a SE of 0.66 larvae.m^{-2}. The tendency of the *Anopheles* larval density was to diminish. In conclusion, EET has an important impact in larval density of *Anopheles* with EET increase associated with larval density decrease. Rev. Biol. Trop. 65 (2): 565-573. Epub 2017 June 01.

Key words: *Anopheles*, larval density, modeling, Equivalent Effective Temperature, Villa Clara, Cuba.

Malaria is a mosquito-borne infectious disease in humans and other animals, caused by apicomplexan parasites that belong to the genus *Plasmodium* Marchiafava & Celli, 1885. These Protozoa spread through the bites of infected mosquitoes mainly of the genus *Anopheles* Meigen, 1818. Nowadays there are five parasite species that cause malaria in humans: *P. falciparum, P. vivax, P. malariae*, *P. ovale* and *P. knowlesi*. Of these, the two first pose the greatest threat, while the last one was recently identified in several African countries (Thomas & Conway, 2004; Cox-Singh, Davis, Lee-Kim & Shamsui, 2008).

This re-emerging and life-threatening disease is responsible for one of the main worldwide health problems, on social and economic scales (Greenwood, 1997; WHO, 2005). Between 2000 and 2015, malaria incidence among populations at risk (the rate of new cases) globally fell by 37 % (WHO, 2016). In that same period, malaria death rates among populations at risk fell by 60 % among all age groups and by 65 % among children under the age of five. According to the latest WHO estimates, released in December 2015, there were 214 million cases of malaria in 2015 and 438 000 deaths, mostly in Sub-Saharan Africa, which carries a disproportionately high share of the global malaria burden (WHO, 2016).

This parasitic disease was successfully eradicated from Cuba as of 1967 and the country was certified “malaria-free” by WHO in November 1973 (OPS-OMS, 1972). However, the intensification of this disease worldwide and the huge flow of people from endemic areas, caused the re-introduction of this disease in the country, possibly through imported cases (Valdés Miró & Marquetti, 2010).

Human malaria is exclusively vectored by culicids of the genus *Anopheles*, however, other *Plasmodium* species are transmitted by other genus as *Aedes* and *Culex* infecting many animal species such as reptiles, birds and various mammals (Cox, 2010). Cuba’s climate is tropical and seasonally wet; with many different mosquito species thriving under these conditions (García, 1997). Of these numerous species, six species fall into the genus *Anopheles* and have been reported from several regions within the country (González, 2006). In this sense, knowledge of the diversity, ecology and synanthropic behaviour of these species is essential for the successful development of vector surveillance and control programs (García, De Jesús, Diéguez, & Estévez, 2008; Fimia-Duarte et al., 2015).

The Effective Temperature (ET) is an empirical indicator of temperature sensation, calculated under the base of air temperature and relative humidity. It has been frequently used and modified since the concept was proposed by Hougthon and Yaglou (1923). The wind chill or Equivalent Effective Temperature (EET) represents the temperature sensation (Brauner & Shacham, 1995), which combines the air temperature, humidity and the wind speed. As is evident, the close interaction between living organisms with their environment, complying with the principles of continuous replacement, the interrelation and biotransformation; to this end, organisms use necessary amounts of substances and energy to achieve their optimal use, for a maximum economy (Cardellá & Hernández, 2005). The objective of this research was to model the wind chill for the meteorological station of Yabu, located in the municipality of Villa Clara named Santo Domingo, and to determine/to establish the possible relation of this indicator with the *Anopheles* larval density.

MATERIALS AND METHODS

Study site: The study was carried out in Villa Clara province, which is located in the center part of Cuba. It is composed of 13 municipalities and limits to the West with Matanzas, East with Sancti Spiritus and South with Cienfuegos. Santo Domingo municipality has a huge net of fluvial ecosystems composed of rivers, brooks, ditches, trenches, lagoons and ponds, natural and artificial, which constitute excellent oviposition sites for mosquito females, in which sampling efforts were focused. The previous information on mosquito breeding sites, gathered by Salaberry et al. (2012), was used in this study for reference purposes.

Period of study and methodology used: Meteorological data, taken every three hours since January 1st, 2011 to September 30th, 2013, were used in this study. A total of 5 370 data corresponding to Yabu meteorological station in Santa Clara (the capital of the province) were obtained, while data from the Santo Domingo station were not available.

The Linear Regression method was used for the analysis (Osés & Grau, 2011); this methodology has been previously used in Cuba to forecast intense earthquakes (Osés et al., 2012a); as well for predicting the larval density of mosquitoes (Fimia et al., 2012a; Osés-Rodríguez et al., 2016).

A long term forecast (1 year in advance) was obtained for the EET. Initially the calculated EET was converted to monthly data to make it coincide with the monthly *Anopheles* larval density data for Santo Domingo meteorological station (Latitude: 22º 58´, Longitude: 80º 22´). All the meteorological data are stored in the Meteorological Centre of Villa Clara, Cuba. This density was modelled using the Linear Regression Objective Regressive (ROR) methodology, including as independent variable the forecasted EET in a monthly basis, and with previous information. The ET and EET calculus was made through Brooks's formula (Bútieva, Ilichiova & Kornilova, 1984), and the complete expressions are:

$$ET= t - G/80\ (0.0043\ T^2+0.456\ T + 9.5)$$
$$EET = ET + W\ [(0.11\ T - 0.13) - 0.002\ TG]$$

where: t: wind temperature. G = 100 - r, where r is the relative humidity air in %. T = t - 37: difference between air temperature and human body. W: wind speed at 2 m of height, which comes from the relation 0.67 V, where V is the wind speed at 10 m of height (at the level of the meteorological station), in m/s. Once ET and EET are known, temperature sensations were established corresponding to the different intervals (Table 1) (Musari, Adewale, & Olonade, 2014). These intervals can be considered appropriate for Cuban population, adapted to warm and humid conditions, and which occur throughout the year in Cuba.

Methodology ROR: The Regression Objective Regressive (ROR) is a widespread method used in meteorology; for example, in the modeling of cold fronts (Osés, Saura, & Pedraza, 2012c). The ROR methodology is also applied to long term prediction of *Anopheles* mosquitoes larval densities (Osés et al., 2012d); besides, a long term-prognosis (1 year in advance) was done to obtain daily forecast of meteorological variables in Sancti Spiritus (Osés et al., 2014). The ROR methodology is suitable to a high band of applications in data series modeling. In this paper, a long term-prognostic (one year) was used to obtain the wind chill in the locality of Santo Domingo, and to relate it with the anophelinic density, to establish a prediction model.

TABLE 1
Intervals of temperature sensation for Cuba, under the base of ET (Effective Temperature) and EET (indicator named *wind chill*)

Interval of ET / EET	Sensation
ET – EET $\leq$ 12 ºC	Very cold
12.0 $<$ ET – EET $\leq$ 17.0	Cold
17.0 $<$ ET – EET $\leq$ 22.0	Slightly cold or cool
22.0 $<$ ET – EET $\leq$ 25.0	Comfortable
25.0 $<$ ET – EET $\leq$ 28.0	Warm
ET – EET $>$ 28.0 ºC	Very warm

RESULTS

Anopheles larval density in Santo Domingo locality was modeled and the EET of Yabu station was included as independent variable (EET_mean), as shown in the model of table 2; variables «ST» (Sawtooth) and «IST» (Inverted Sawtooth) were significant. This model explained the 66 % of the variance with an SE of 0.06 larvae/m^2.

Figure 1 shows the frequency distribution of residuals following the nearest to normal distribution that is good for the model. In figure 2, some spaces in an almost straight line can be observed, between the expected probability and the observed probability of standardized residuals, very useful for the model.

The model using the Regressive method of EET (as dependent variable), accounted for 97.1 % of the variance in data (R2 = 0.97)

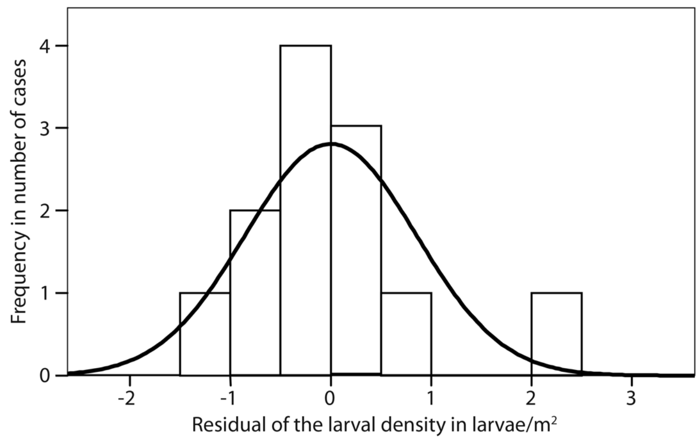

Fig. 1. Frequency distribution of Residuals with Regressive Methodology. Dependent variable: Santo Domingo *Anopheles* larval density. Mean = 1.54E-15 / Standard Deviation = 0.853 / N = 12. The term «residual» means the difference between the real and the predicted values in the sample of 12 cases.

with a SE of 3.72C (test stats); the statistics of Durbin Watson was 0.92, existing correlation between the SE because the prediction data are used with one year in advance.

Predictor variables were EET of the previous year: «Step4207» is the case number 4207 that had an important impact in the modeling; «ST» and «IST» were dichotomous variables; «Stepmenor1» represented the variable that captured the impact of the residuals that were minor than 1 larvae/m^2; «Lag2959TEE», «Lag2922TEE», «Lag2935TEE», «Lag-2920TEE», «Lag2926TEE», «Lag2923TEE», «Lag2921TEE» and «Lag2927TEE» were the lag variables of EET in a previous year; and «NoC», which is the tendency of the model. Variance analysis was significant to the 100 %, with an F of Fisher of 5 751.115.

The model for this stage can be observed in table 3, where «ST» and «IST» explained the ups and downs of the series, being both significant to the 100 %. The variables

TABLE 2
Regressive model of *Anopheles* larval density in Santo Domingo, Cuba

Model 1	Coefficients B	t	Sig.
ST	0.451	3.32	0.011
IST	0.452	3.36	0.010
NoC	-0.011	-1.93	0.089
TEE_mean	-0.015	-2.17	0.061

Dependent Variable: STODOMDLA. Linear Regression through the Origin. *t* = T Student Test. Sig = Significance.
ST = 1 if NoC is an even number and ST = 0 if NoC is an uneven number (dichotomous variable).
IST = 0 if NoC is an even number and IST = 1 if NoC is an uneven number (dichotomous variable inverse to ST).
NoC is the number of the case and its coefficient is the tendency of the series.

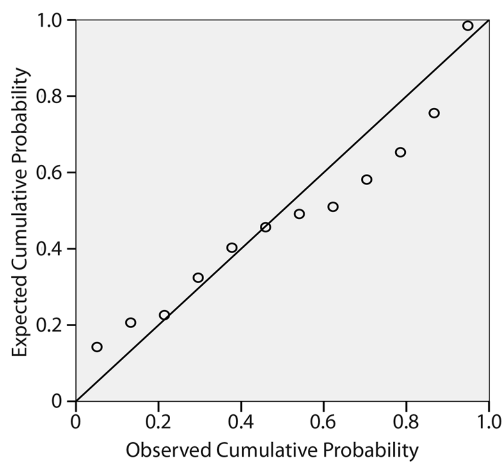

Fig. 2. Plot of probabilities of residuals with Regressive Methodology. In a perfect model all the points should be over the straight line where the Expected Cumulative Probability should be equal to the observed Cumulative Probability. Little deviations exist but are acceptable because the points are close to the straight line.

TABLE 3
Regressive Modeling of EET
(indicator named *wind chill*)

Model 1	Coefficients B	t	Sig.
ST	3.493	7.71	0.000
IST	3.271	7.22	0.000
NoC	0.003	17.95	0.000
Lag2920TEE	0.136	6.59	0.000
Lag2921TEE	0.072	3.26	0.001
Lag2922TEE	0.037	1.69	0.090
Lag2923TEE	0.042	2.06	0.039
Lag2926TEE	0.093	4.60	0.000
Lag2927TEE	0.043	1.94	0.052
Lag2935TEE	0.020	0.98	0.318
Lag2943TEE	0.086	4.50	0.000
Lag2959TEE	0.041	2.36	0.018
Stepmenor1	-22.345	17.61	0.000
Step4207	-18.908	4.97	0.000

Dependent Variable: EET. Linear Regression through the Origin. *t* = T Student Test. Sig = Significance.
ST=1 if NoC is an even number and ST=0 if NoC is an uneven number (dichotomous variable).
IST=0 if NoC is an even number and IST=1 if NoC is an uneven number (dichotomous variable inverse to ST).
NoC is the number of the case and its coefficient is the tendency of the series.
Lag2920TEE, is lag1 of TEE, but the value of the previous year.

that influenced in EET modeling were regressive EET in 1, 2, 3, 4, 7, 16, 24, 40, but one year in advance, that is, «Lag2920TEE» corresponded to lag1, «Lag2921EET» corresponded to lag2, and so on.

Finally, the real and predicted values for modeling ROR of *Anopheles* larval density were plotted with EET mean as independent variable (Fig. 3), observing a great coincidence between real and predicted values during the modeling stage.

DISCUSSION

In first place, it is noted a strong contagion between the data with respect to the previous year, namely great correlation of the EET with the EET data to the previous year. This is because these variables were significant with one year in advance, except «Lag2935TEE», besides the variables Step, which evaluated the importance of the different cases sampled. In particular, «Stepmenor1» evaluated the impact of the cases, in which the difference between the real value and the predicted was lesser than -1 ºC. The variable «Step4207» is an important

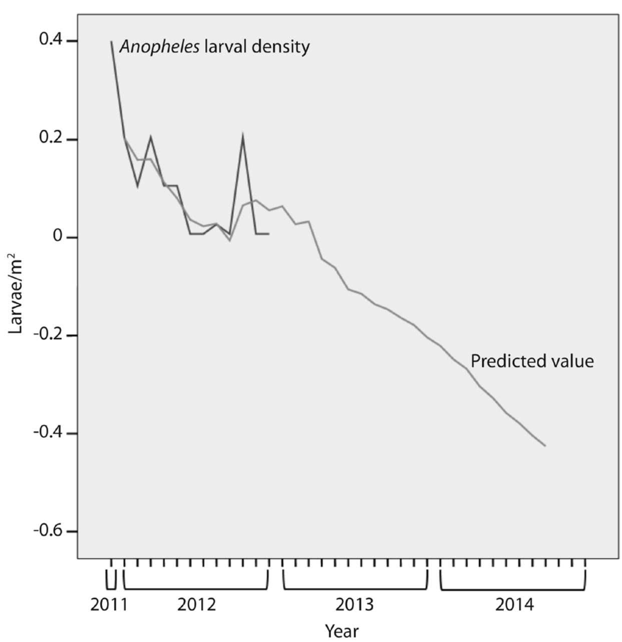

Fig. 3. Results of real and predicted values of *Anopheles* larval density.

particular case in the sample that present great error, more than 3 standard deviations, so it can be considered an outlier; the tendency in time increased significantly, which corresponds with the presence of a climate change for temperature, according to the International Governmental Panel of Climate Change (IGPCC, 2007).

As can be seen, the standardized residuals presented media 0 and standard deviation 0.997 near to 1, the maximum residual was of 10.39, and resulted lesser than a short-term model (Osés et al., 2012d).

The tendency («NoC») is to decrease. It can also be highlighted the correspondence with other papers (Osés, Bonet, Cepero, Saura, & Pedraza, 2010), where temperature is a variable that impacts in total larval density; such results coincide with other authors in fluvial ecosystems of Santa Clara municipality, as well as from the province (García et al., 2012; Osés et al., 2012b). In general, despite known associations between developmental traits and factors of diet and density, temperature has been considered the primary driver of development rate and survival in preimaginal stages and imago mosquitoes (Couret, Dotson & Benedict, 2014).

The results obtained for the larval density of mosquitoes are in accordance with those achieved by García et al. (2012) and Osés et al. (2012b), showing that climate change affects the temporal and spatial distribution, as well as the seasonal dynamics of pathogens, vectors, hosts and reservoirs. High temperatures and rainfall contribute to the formation of mosquito breeding sites and change the life cycles of these insects, which is consistent with results obtained by Eisen, Bolling, Blair, Beaty and Moore (2008), OPS (2008) and Gage, Burkot, Eisen and Hayes (2008). Accordingly, vector-borne diseases are also highly sensitive to changes in weather and climate (Medlock & Leach, 2015); there is no doubt that the results are extrapolated to the adult stage, not only in mosquitoes but also to other groups such as nematocerans with aquatic stages. Confirming once again the principles/precepts of continuous exchange of substances, energy and information with the surrounding medium (continuous parts), where all metabolic processes are interrelated. This constitutes a single undertaking (the interaction), allowing different responses to stimuli environment (biotransformation), and for which bodies are endowed with efficient regulatory mechanisms, that ensure various processes, only with the required quantity of substances and energy. Besides, we used the terms maximum economy, in accordance with Cardellá and Hernández (2005).

The mathematical model of the larval density of Santo Domingo municipality explained the 97.1 % of variance with a Standard Error (SE) of 3.57 ºC for EET model, with one year in advance. Tendency in time was significantly increasing for EET. Most important variables in the model were the regressive EET in 1, 2, 3, 4, 7, 16, 24, 40 of the previous year that is 2920, 2921, and so on, explaining a strong contagion between data, namely a great correlation between the data Lag1 and so on, with the data in the previous year. Anophelinic density model in Santo Domingo, Cuba, explained the 66 % of variance with an error of 0.06 larvae/m^2. It can be stated that if tendency continues, then *Anopheles* larval density must keep on decreasing in the future in this locality. The control of the bias of other factors such as rain is also relevant. In this case we can say that according to the length of the data series of larval density, the rain should not impact, because a 30 years period is required to obtain a stationary series of data (WMO, 1983). Regarding the above-mentioned, it is evident that EET has an important impact in the larval density of *Anopheles*.

Although malaria was eradicated in Cuba almost 50 years ago, climate change and global warming, and the subsequent changes in temperature, rainfall and humidity, as well as extreme events, are expected to influence considerably the spread of infectious diseases, particularly vector-borne diseases (Sutherst, 2004). In addition, the main vector of malaria in Cuba, *An. albimanus*, is one of the most widely distributed species in the province (Fimia-Duarte et al., 2015).

In conclusion, by the means of mosquito larval density and the use of mathematical modeling, it is possible to do some prognosis to model both general and specific larval density (*Anopheles*), at short, medium and long time terms. This enable us to create an integrated surveillance programme, which is a critical component of an early warning system, that may allow vector control staffs to undertake certain and opportune and economical actions, which are undoubtedly a contribution to epidemiological analysis for vector-borne diseases (Fimia, Osés & Otero, 2012b; García et al., 2012; Osés et al., 2012c).

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RESUMEN

Modelación de la Temperatura Efectiva Equivalente y posible incidencia en la densidad larval de mosquitos *Anopheles* (Diptera: Culicidae) en la provincia Villa Clara, Cuba. La Temperatura Efectiva Equivalente (TEE) es la sensación térmica que siente una persona frente a una determinada combinación de temperatura del aire, humedad relativa y velocidad del viento. El objetivo de la investigación fue determinar la posible incidencia de la TEE sobre la densidad larval de mosquitos del género *Anopheles* en la provincia Villa Clara, Cuba. Una base de datos recogió medidas climatológicos cada tres horas durante el periodo comprendido entre el 1 de enero 2011 hasta el 30 de septiembre 2013, proveyendo un total de 5 370 medidas de la estación Yabú de Santa Clara. Se realizó un pronóstico a largo plazo (1 año) para obtener la TEE y se modeló la densidad larvaria total de mosquitos en la localidad de Santo Domingo. Los datos entomológicos fueron recogidos en el mismo lapso temporal pero con una periodicidad mensual, por lo que los datos de TEE fueron convertidos a escala mensual para poder ser empleados con los datos de densidad larvaria. Para la modelación se utilizó la Metodología de Regresión Objetiva Regresiva que explicó el 97.1 % de varianza con un error estándar (SE) de 3.57 ºC para el modelo de TEE con un año de antelación; la tendencia en el tiempo fue significativa al aumento. Además, al modelar la densidad larvaria anofelínica en el municipio Santo Domingo, se observó que a medida que aumenta la TEE, disminuye la densidad larval anofelínica. La variable más importante en el modelo fue la TEE regresada en 1, 2, 3, 4, 7, 16, 24, 40, pero del año anterior, es decir 2 920, 2 921, y así sucesivamente, explicando un contagio muy fuerte entre los datos. Ello fue debido a que la correlación de TEE con ella misma en años anteriores fue alta, por lo que puede ser utilizada como variable predictora. El modelo de densidad larval anofelínica en Santo Domingo explicó el 66 % de la varianza, con un SE de 0.06 larvas/m^2. La tendencia de la DLA fue a la disminución. En conclusión, la TEE tuvo una incidencia directamente proporcional en la densidad larval anofelínica, ya que a medida que aumentaba este indicador, disminuyó la densidad larval anofelínica.

Palabras clave: *Anopheles*, densidad larval, modelación, Temperatura Efectiva Equivalente, Villa Clara, Cuba.

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